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ABSTRACT

This module sketches out the impact of sewage organic matter on soils. For convenience, that organic matter is separated into the readily decomposable compounds and the more resistant material (volatile suspended solids, refractory organics, and sludges). The fates of those organics are reviewed along with loading rates and recommended soil conditions. Laboratory studies indicate that some soil systems are capable of oxidizing as much as 8000 lbs COD/acre-day if surface clogging is avoided, macropore space is sufficient, optimum moisture levels are maintained, and adequate soil aeration is assured. More stable organic matter generally is not present in quantities that are significantly greater than the normal losses from productive soils. Usually the actual amount of organic matter that is added through land application is small compared to the amount of native organic matter present. Also, the newly added organic matter decomposes more rapidly than native organic matter. These factors, combined with the restrictive load limits imposed by the nitrogen content of wastes, keep the net accumulation of organic matter quite low in highly productive soils. (Author/BB)

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An Educational Program

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ORGANIC MATTER

Module 17

January, 1978

SE 025 031

LAND APPLICATION
OF WASTES -
AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

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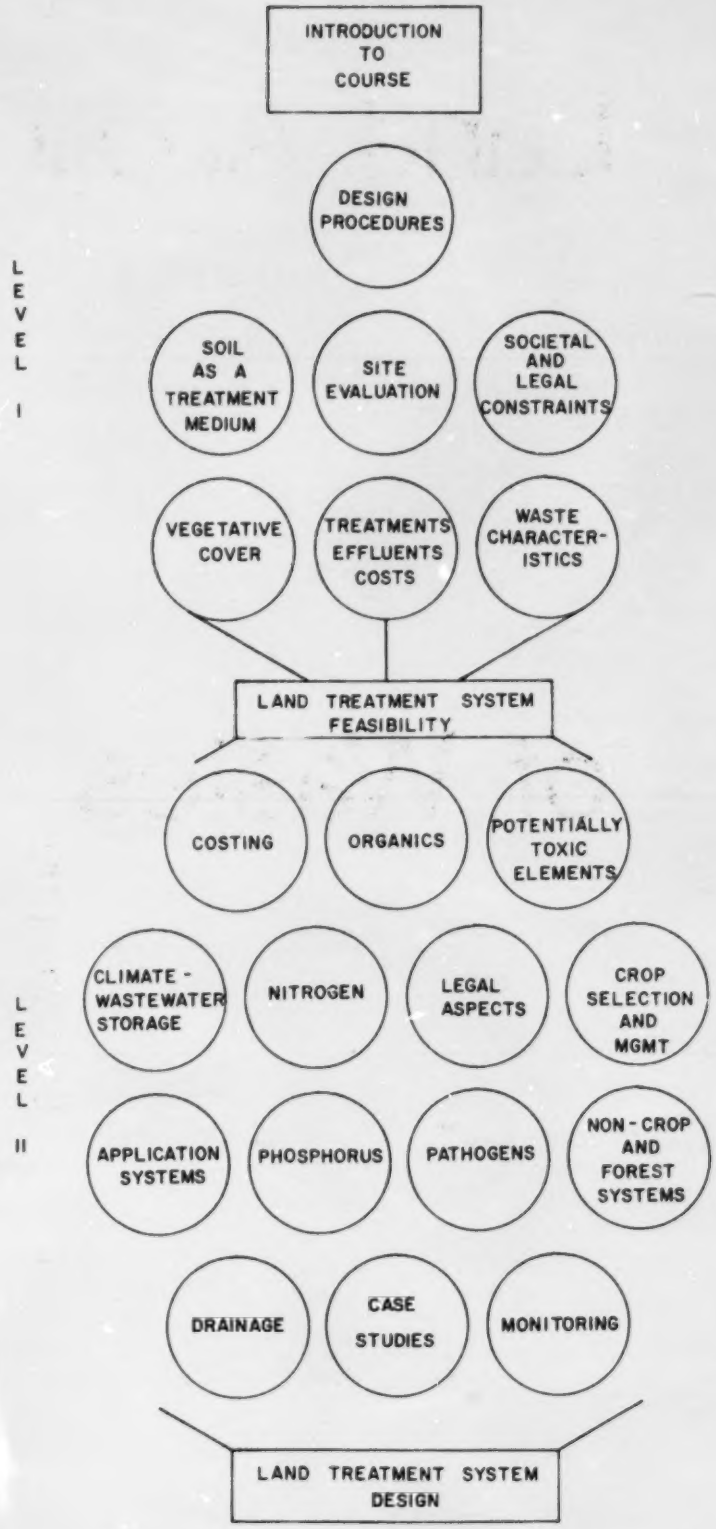

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ORGANIC MATTER

Module 17

January, 1978

Summary

This module sketches out the impact of sewage organic matter on soils. For convenience, that organic matter is separated into the readily decomposable compounds (measured as BOD_5 or COD) and the more resistant material (volatile suspended solids, refractory organics, and sludges). The fates of those organics are reviewed along with loading rates and recommended soil conditions.

Laboratory studies indicate that some soil systems are capable of oxidizing as much as 8000 lbs COD/acre-day if surface clogging is avoided, macropore space is sufficient, optimum moisture levels are maintained, and adequate soil aeration is assured.

More stable organic matter generally is not present in quantities that are significantly greater than the normal losses from productive soils. Usually the actual amount of organic matter that is added through land application is small compared to the amount of native organic matter present. Also, the newly added organic matter decomposes more rapidly than native organic matter. These factors, combined with the restrictive load limits imposed by the nitrogen content of wastes, keep the net accumulation of organic matter quite low in highly productive soils.

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Glossary

acclimated microorganisms - Any population of microorganisms which is adapted to certain environmental conditions. Used to refer to bacteria which are exposed to a particular substrate before being used in the BOD_5 analysis on a sample of that substrate.

biodegradation - The breakdown, by microorganisms, of complex organic compounds in a substance to their constituent elements or compounds.

BOD - Biochemical oxygen demand. The amount of dissolved oxygen required to meet the metabolic needs of microorganisms utilizing organic substrate in a water sample of known volume. Used as an indirect measure of the biodegradable organic matter content of the sample.

BOD_5 - Five day biochemical oxygen demand test. Oxygen consumption is measured over a 5-day period. The standard laboratory BOD analysis for most applications.

bulk density - The mass of powdered or granulated solid material (such as soil) per unit of volume.

COD - Chemical oxygen demand. The oxygen equivalent of that portion of organic matter in a sample susceptible to oxidation by a strong chemical oxidant.

denitrification - The breakdown of nitrate or nitrite to gaseous products such as nitrogen, nitrous oxide, and nitric oxide. Brought about in anaerobic conditions by denitrifying bacteria.

field capacity - The moisture content which a soil will retain against the force of gravity, i.e., when all macropores have drained but micropores remain saturated.

macropore space - The total volume of soil pores which are of large enough size that water is not held in them by capillary attraction.

micropore space - The total volume of soil pores which are small enough to hold water by capillary force over the force of gravity.

nitrification - Oxidation of ammonium salts to nitrites and oxidation of nitrites to nitrates by certain bacteria.

NOD - Nitrogenous oxygen demand. Utilization of free oxygen by certain autotrophic bacteria to oxidize ammonia to nitrite and nitrate, usually exerted from 6 to 10 days after the start of a BOD analysis. Also known as second-stage BOD.

PCB - Polychlorinated biphenyl. A synthetic organic compound used in several manufacturing processes. Persistent in the environment - resists degradation.

substrate - Source of nutrients used by a microbial population for biological synthesis.

Objectives

Upon completion of this module, the reader should be able to:

1. List several management practices which can have beneficial and harmful effects on soil aeration capacity.

2. State the major problem, and one factor which minimizes its harmful effects, related to most synthetic organic compounds released to the soil in waste treatment sites.

3. Explain the relationship between carbon to nitrogen ratio and decomposition of organic matter.

4. Discuss briefly the typical impact of applying waste organics to the soil, in terms of the proportion of applied mass to the mass of native soil organics.

5. List some types of areas which may be reclaimed or stabilized through application of waste organic matter.

Introduction

Organic material is always present in raw domestic sewages. In general, this organic matter is responsible for odors and for oxygen depletion in receiving waters or soils. Therefore, organic matter must be accounted for and managed properly if a given treatment system is to be successful.

The designation "organic matter" includes a wide variety of chemicals. To simplify the discussion here, organic matter is separated into two categories: that which is generally water soluble and readily biodegradable and that which is insoluble and more resistant to biodegradation. The first category is loosely identified as the BOD_5 component while the second is the volatile suspended solids, refractory organics and sludges.

In this module, a short review of the distribution and chemical classification of sewage organic matter is followed by more specific comments regarding the impact of BOD_5 organics in soil systems. Consideration is given to soil conditions, microbial populations, nutrient ratios, loading rates and application practices.

A final section of this module considers the more resistant organic matter of sewages and sludges. These will be reviewed in terms of their implications to soil systems and their fates after land application. Attention is given to the effects of sewage organic matter on soil aggregation, humus buildup, toxic element retention, and soil clogging.

Adoption of "acceptable" organic loading rates based on design parameters used in oxidation lagoons and other treatment processes is not good practice. The assimilative capacity of acclimated soil should be determined for the particular waste under study. Recent treatability studies with high organic wastes have shown assimilative capacities far in excess of common empirical guidelines for waste loadings.

Organic Matter of Untreated Wastewaters

Various readers can be expected to differ in their interpretations of what constitutes the "organic matter" of untreated wastewaters. A rather abbreviated listing of specific components appears in Figure 1.

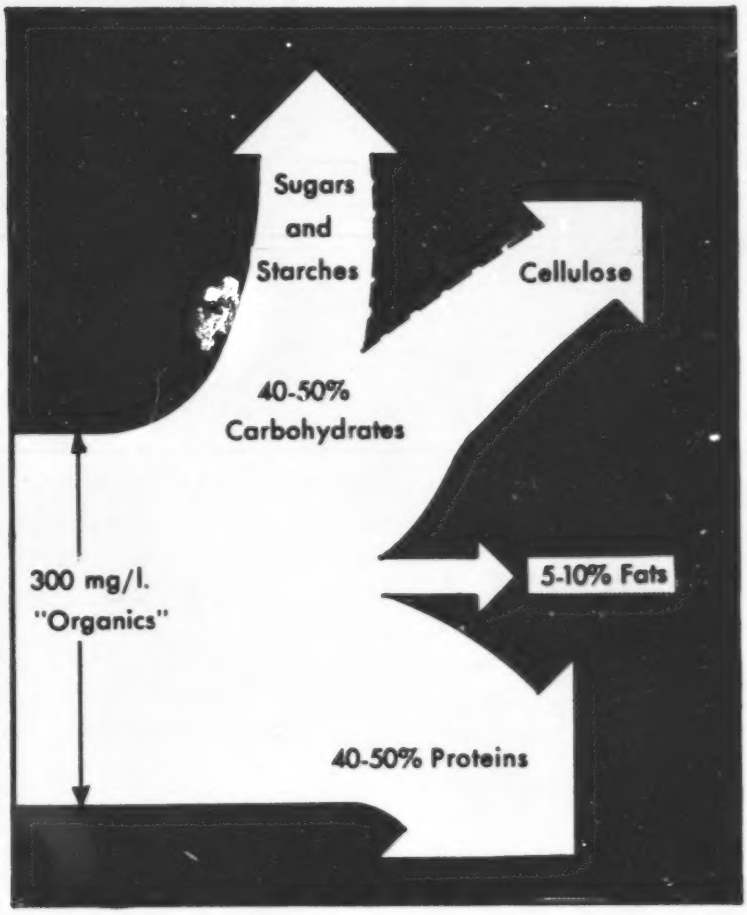

Figure 1

The organic matter of untreated wastewater is primarily carbohydrates, proteins, and fats (adapted from McKinney, 1962).

Categories of Organic Matter:

For the purposes of this module, some rather simplistic generalities will be used to avoid misunderstandings and to center the discussion on more pertinent issues. One of the generalities will be to divide organic matter into soluble and insoluble components. That division is illustrated in Figure 2.

Organic matter can be classified roughly as soluble and insoluble.

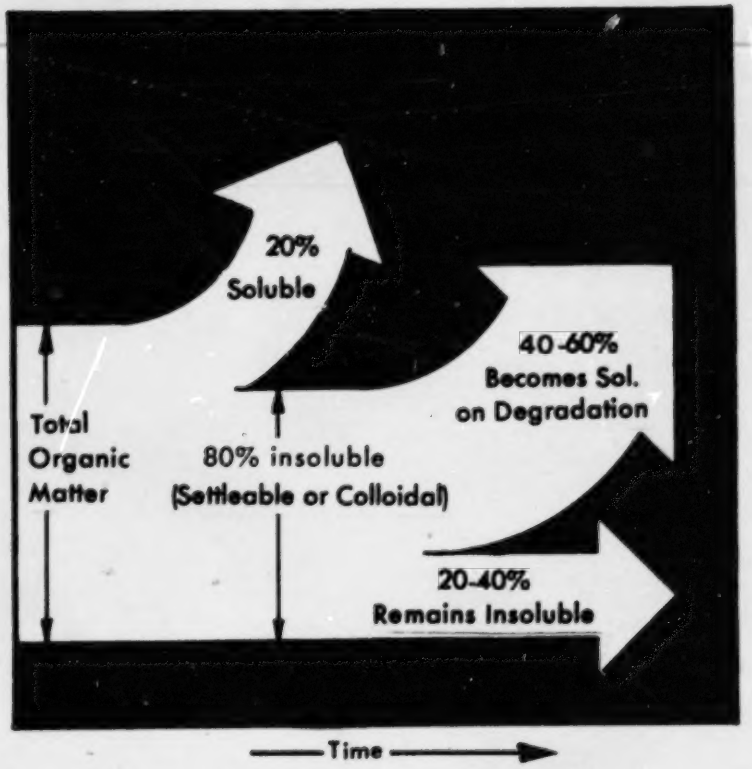

Figure 2

The amount of organic matter in untreated wastewater that is or becomes soluble exceeds the amount that remains insoluble (adapted from McKinney, 1962).

The second generality is to divide organic matter in terms of the relative demand for oxygen which the different forms impose on the environment. In this respect, three categories of wastewater components are easily identified.

The first category includes the organics that exert a high biochemical oxygen demand. These are often soluble and are measured by the standard BOD_5 methods. Occasionally wastewaters of municipalities or food processing industries carry substances that may or may not be detectable in the BOD_5 analysis yet which exert a high chemical oxygen demand (COD). The second category includes the proteins. These organics are reduced to ammonia (NH_3) which, in turn, exerts an oxygen demand measured as the nitrogenous demand portion of the BOD, occurring usually after 5 days and sometimes referred to as NOD. The third category includes the less active, usually insoluble organics with no rapid demand for oxygen. When necessary, the impact of these organics may be estimated indirectly by measurements such as Theoretical Oxygen Demand (ThOD), Total Oxygen Demand (TOD), Theoretical Organic Carbon (ThOC), and Total Organic Carbon (TOC).

Organic compounds can be further categorized by the analytical techniques used to measure them.

Oxygen Uptake Patterns:

For the purposes of this module, the familiar BOD_5 data are useful for estimating the impact of readily degradable organic matter in land systems. The reason for this is that decomposing matter demands the same amount of oxygen from soils as it does from aquatic systems. Therefore, as an initial point, consider the BOD_5 oxygen uptake pattern reproduced in Figure 3. Note that the most rapid uptake of oxygen occurs in about the first two days. Then there is a marked decrease in uptake rate, but, of course, a continuing increase in total demand.

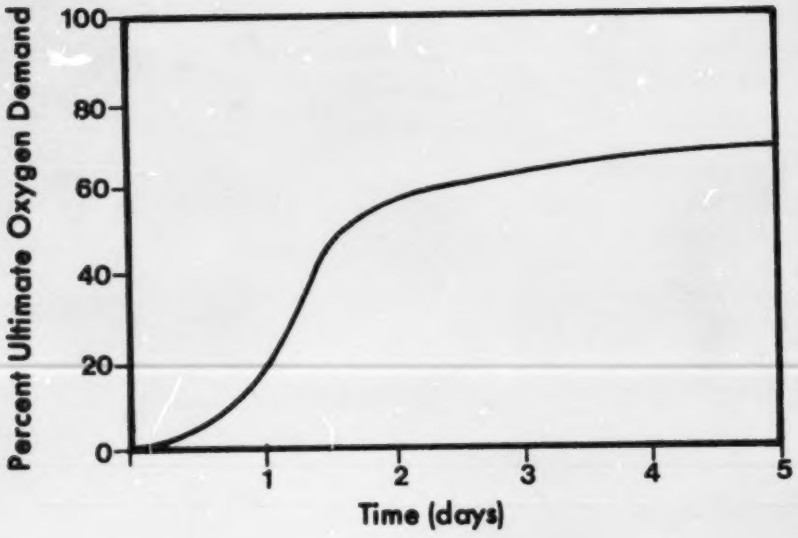

Figure 3

Between 65 and 70 percent of the total oxidizable organic matter in typical municipal wastewater is represented by the BOD_5 value (adapted from McKinney, 1962).

If the oxygen demanding organic matter is placed in an acclimated environment (one already populated with microorganisms ideally suited for the substrate) the initial rate of oxygen uptake may be increased dramatically. The ultimate total oxygen demand, however, will not be substantially different (Figure 4). Note that acclimated systems place substantial immediate demands on the oxygen reservoir of an environment. Unacclimated systems respond more slowly and have a reduced rate of oxygen uptake. This is the reason that the laboratory analysis for BOD_5 is always done with bacteria which are acclimated to the wastewater under investigation. In this way a much closer approximation to ultimate BOD can be determined, as shown in Figure 4.

Microorganisms acclimated to the organics will show more rapid uptake of oxygen than those which are unacclimated. This is a basic premise used in the BOD_5 laboratory analysis.

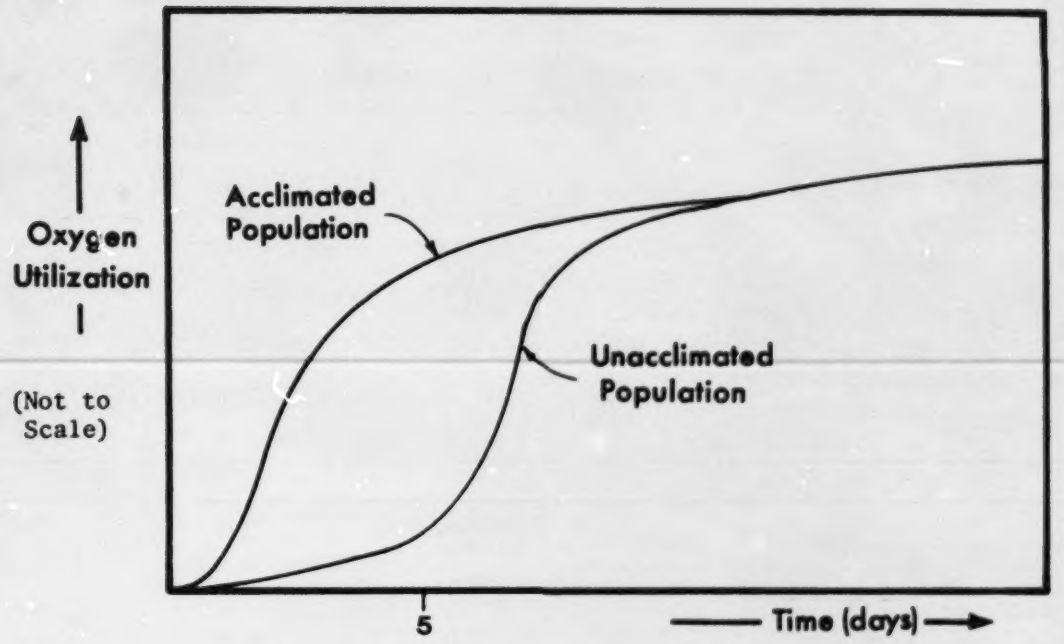

Figure 4

Microbial populations unacclimated to the substrate exhibit significant lag times before oxygen uptake occurs (adapted from McKinney, 1962).

Significance to Land Application:

The BOD_5-exerting organics consume large volumes of oxygen very rapidly, so it is not unreasonable to wonder if the soil environment can satisfy that demand. Laws that limit BOD_5 application rates to about 5,000 mg/l (600 lbs/acre-day) apparently reflect the thought that the capacity of soil to meet oxygen demands approximates that of common lagoons (Jewell and Loehr, 1975). In the following section, however, it will be shown that the premise may be unnecessarily conservative for at least some wastewaters. There is an appreciable body of evidence indicating that soils can supply sufficient oxygen to compete directly with

secondary treatment systems with a variety of wastewaters.

The third section of this module concentrates on the fate of the more slowly decomposable organic matter of wastewater and sludges. It will be shown that their accumulation on productive soils is not excessive.

Response of Soil Systems to Organics:

Amending soils with high BOD_5 wastes poses a stress on the available oxygen within the soil system. As long as that oxygen demand can be met, the BOD_5 load will not be excessive. But meeting that load requires the interaction of several complex events. In the following paragraphs we will first focus on the response of soils to BOD_5 loading, then on those factors that influence that response.

Organic Loadings and Soil Responses:

Wallace (1976) reported that land disposal systems existing at the time of his publication handled industrial wastes ranging from 10 to 2,020 lbs BOD_5/acre-day. He did not stipulate the adequacies of treatment acheived. Wallace did cite lysimeter studies that indicated 100% BOD removal from sulfite liquor wastes at low concentrations (< 150 lbs BOD_5/acre-day) under aerobic conditions. Gross organic overloads of that same industrial waste appeared at surface loadings approximating 1,000 lbs BOD_5/acre-day (Figure 5).

Jewell and Loehr (1975) reported results of a study in which food processing wastewater was added to soil in a Warburg apparatus. The rate of oxygen uptake was determined for both acclimated and unacclimated soils, each under various COD loadings. Partial results are given in Figure 6. Note the similarity between Figure 6 and the previous discussion on acclimation.

Laboratory studies show that acclimation of soil bacteria to a particular waste greatly increases the soil's capacity to treat organic wastes effectively.

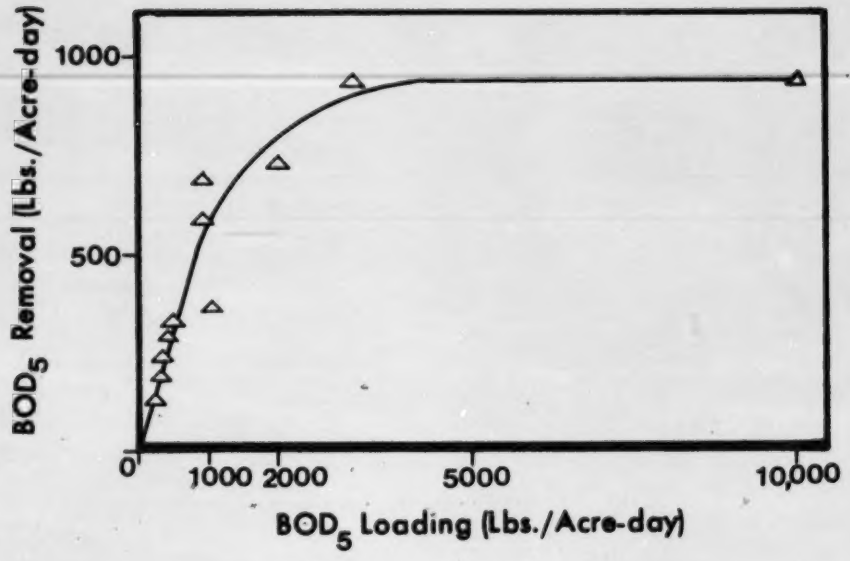

Figure 5

BOD_5 removal from sulfite liquor loadings onto 10 foot soil columns had a marked decrease in efficiency at loadings greater than about 1000 lbs/acre-day (adapted from Wallace, 1976).

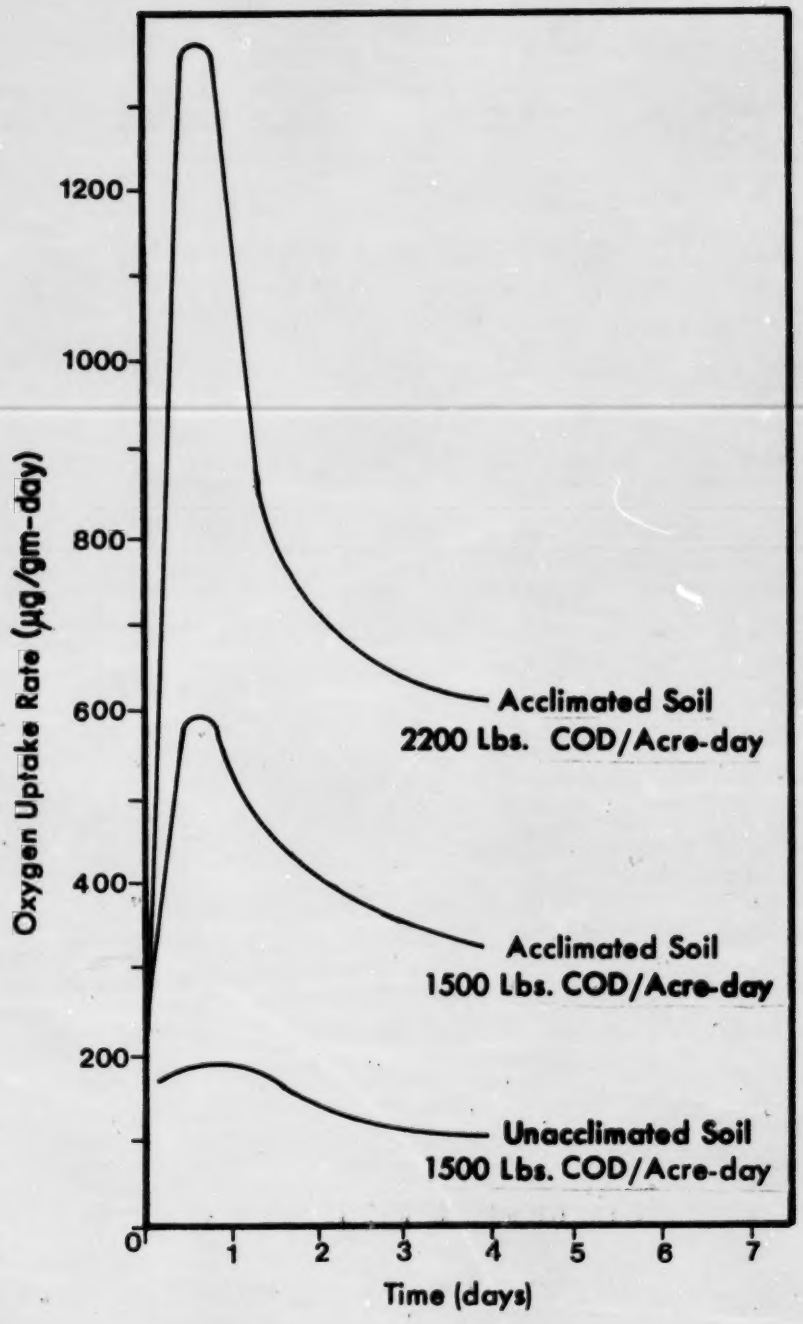

Figure 6

Oxygen uptake rates increase rapidly when soil is acclimated to large COD loadings of food processing wastewater, yet no point of organic overloading is reached at less than 2200 lbs COD/acre-day (adapted from Jewell and Loehr, 1975).

Here again the effects of acclimation are to increase the rate of oxygen uptake and even allow a rapid adjustment to excess loading. Note also that in each case the respiration has passed its maximum rate in less than two days.

Jewell and Loehr concluded that the soils studied retained the potential of accepting food processing wastes from vegetable canning at concentrations of 10,000 mg/l COD without suffering organic overloading. The reported oxygen uptake rate at various soil organic loadings is given in Figure 7. Note the massive loadings

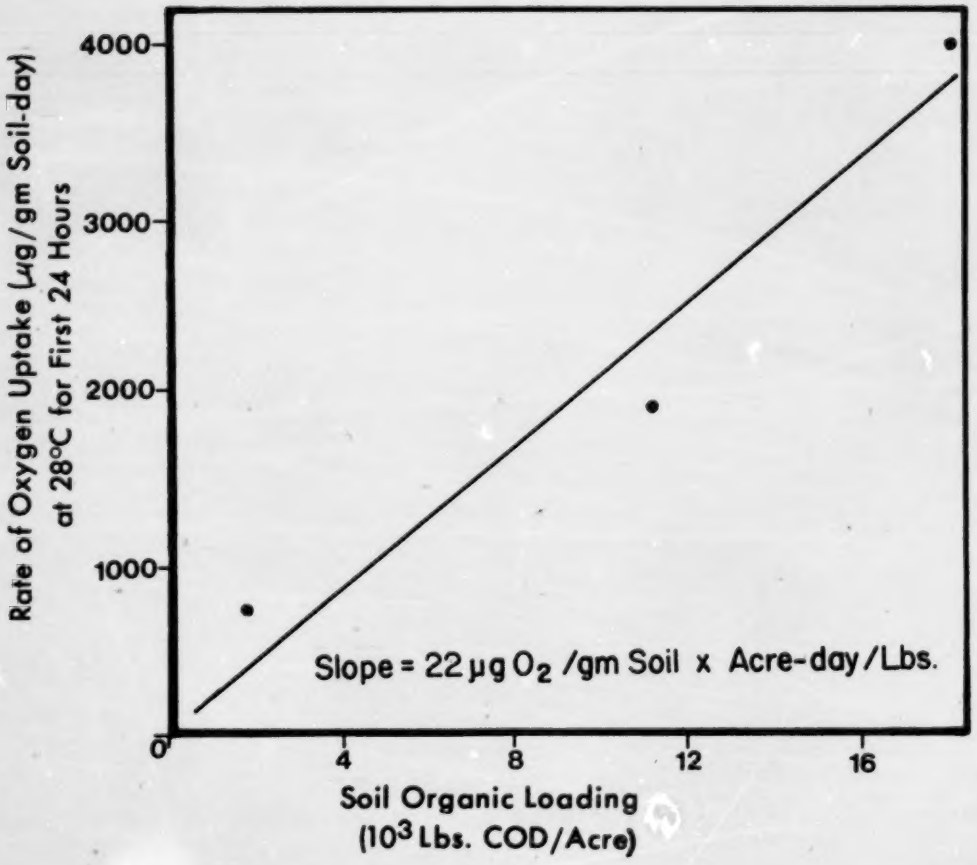

Figure 7

Soil organic loadings of food processing wastes led to no organic overloads even with loads exceeding 16,000 lbs COD/acre-day in laboratory studies (adapted from Jewell and Loehr, 1975).

reported in these data. Recall that some laws prohibit BOD_5 loads in excess of 600 lbs/acre-day from land application. Also, compare with Wallace's data for industrial waste (Figure 5) and consider the implications suggested regarding the appropriateness of specific wastes for land application.

Ultimate Fate of Organics in Soils:

Although usually the maximum exertion of BOD by organic wastes occurs in the first 48 hours or so after application (Jewell and Loehr, 1975), that does not indicate that total oxidation has occurred. Total oxidation means that all organics would be reduced to the ultimate respiratory products: carbon dioxide and water. It is clear from Figure 6 that even after 5 days the respiration rates in the test samples exceeded initial rates, hence substantial amounts of substrate survive at least that long. In fact, some of the original oxygen-demanding organic matter still may be present. Most of the organic matter that is oxidized, however, is converted to gums, slimes, protoplasm, and other metabolic by-products by the soil microorganisms. These by-products, particularly the gums and slimes, have important if temporary roles in the formation of soil aggregates (Allison, 1968) before they, too, are degraded (Martin, et al., 1965).

Metabolic by-products of microbial decomposition can help form soil aggregates before they also undergo decomposition.

The degradation of waste organics and metabolic by-products increases the percentage of soluble organics (review Figure 2). This raises concern for the possibility of contaminating groundwater with waste organics. However, field studies from a vegetable processing plant reported by Jewell and Loehr (1975) show that this should not be of concern in a well-acclimated system. Even at an initial one-day loading of 8,000 lbs COD/acre (1,300 lbs/acre-day average rate with 5 days rest between applications) a 99.2% removal of COD was achieved. Less than 35 mg/l total COD reached the groundwater from that loading.

Wallace (1976) reviewed data (presented in Figure 5) showing that if soils are forced to anaerobic conditions, only about 10% of the total BOD_5 load may be oxidized (although 100% of the simple sugars are oxidized) and presumably, the remainder remains mobile enough to pose a hazard to groundwater.

Oxygen Reserve of Soils:

The bio-oxidation of waste organics relies on the reservoir of oxygen within the soil. That oxygen supply is extremely variable, of course, but something of its magnitude can be suggested by an illustration.

A well structured silt-loam surface soil at optimum moisture for plant growth may contain around 50% pore space shared equally by air and water. If it is assumed that 30% of that pore space is macropore space and that the soil is homogeneous throughout the first foot, then one acre-foot contains about 3300 cubic feet of soil gases. If the oxygen content of those gases averages, say, 19%, there are some 44 pounds of oxygen present. This clearly is inadequate for even the 600 lbs BOD_5/acre-day limited by some laws.

Therefore, even though the work of Jewell and Loehr (1975) shows that soils have a capacity for bio-degrading large BOD_5 loadings, *in situ* soils face limitations imposed by available oxygen. Soils cannot practically be mechanically aerated. Therefore, soil systems must rely heavily on the diffusion of oxygen from the atmosphere. Despite its extreme importance, however, that diffusion cycle itself is quite simple.

Soils depend on diffusion of oxygen from the atmosphere to replenish available oxygen for soil organisms.

The respiration of soil organisms reduces the partial pressure of oxygen in macropores and increases the partial pressure of carbon dioxide. Since the atmosphere is connected to the macropores, the higher partial pressure of oxygen in the atmosphere acts as the driving force to transport oxygen through the soil

barrier into the macropore space. Similarly, the partial pressure of carbon dioxide within the macropores exceeds the partial pressure of carbon dioxide in the atmosphere, and carbon dioxide is driven across the soil barrier to the atmosphere (Brady, 1974).

The oxygen diffusion rate (ODR) varies with soils and soil depth but a representative soil and its ODR are given in Figure 8. Note that the ODR varies with atmospheric oxygen concentration. Clearly, this is not a major concern over the ranges in oxygen variation likely to be encountered in field work. Generally an ODR of 1.7×10^{-2} pounds of oxygen per acre-minute is needed to sustain vigorous root growth, so the depth at which that limit is reached indicates the approximate maximum depth of root growth and, by implication, the maximum depth for major aerobic respiratory processes for microorganisms.

Oxygen diffusion rate varies with soils and soil depth. ODR affects root depth.

It must be recognized, however, that suspended organic matter does not tend to be distributed uniformly in soils. Rather, it is filtered out in the initial few centimeters. This means that the maximum oxygen demand will have to be met relatively near the soil surface where ODR's are the highest. Therefore, while the ODR may decrease more or less linearly with depth (Figure 8) the actual oxygen demand imposed by wastes may be very high near the surface but rapidly diminish with depth.

Management for Organic Loadings:

The above discussions emphasize the need for maintaining aerobic conditions in soils. This, in turn, requires management which encourages the generation and maintenance of macropore space and a maximum rate of diffusion. Specific practices are reviewed in the following paragraphs.

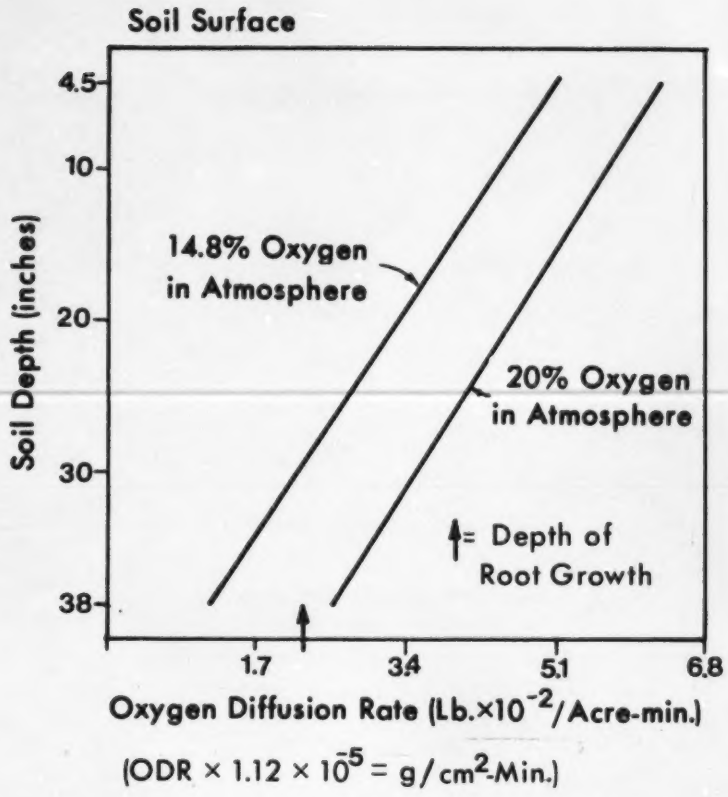

Figure 8

The oxygen diffusion rate (ODR) decreases with soil depth, and root growth terminates where the ODR approximates 1.7×10^{-2} lbs oxygen/acre-min (adapted from Brady, 1974).

Resting periods in an application cycle are necessary for soil aeration to maintain aerobic conditions.

Resting periods: It is common practice to alternate periods of surface application with periods of rest. The rest period is necessary to allow the soil to relieve its hydraulic load, of course, but is also a period for soil aeration. A common schedule is one day application and four to seven days rest (Jewell and Loehr, 1975). Nevertheless, resting schedules are site specific. It may be necessary to determine the optimum oxygen loading and oxygen consumption, and to rely on oxygen diffusion rates to estimate the length of

needed resting periods. The consultation of qualified soil scientists would be needed for such work.

A number of mathematical models have been postulated to help determine loading rates and schedules, but verification data from field studies are, as yet, scarce (Wallace, 1976).

Pore space: One of the most important soil features affecting aeration is micropore space. In this respect, fine textured soils (in which micropore spaces predominate) are least desirable. A well-granulated silt loam surface soil at optimum moisture for plant growth is the most desirable (Brady, 1974).

Loosening and granulating fine-textured soils promotes aeration by raising the proportion of the macropores. On the other hand, continuous cropping, particularly of soils originally high in soil organic matter, often results in a reduction of large macropore spaces by as much as one-half (Brady, 1975). This is attributed to the loss of soil organic matter - a topic to be considered in more detail later in this module. Compaction of soil by machinery or even large grazing animals can further reduce soil macropore space. The sodium and potassium ion concentrations in some untreated wastewaters may be sufficient to cause the destruction of the soil aggregates. Since soil aggregation is so critical to soil structure, destruction leads to massive loss of macropore space. Tillage may have good short term effects on surface macrospace, but over time it promotes the destruction of soil granules and the oxidation of soil organic matter, both of which reduce macrospace. Moreover, the appearance of good tilth after tillage is often achieved at high cost in overall performance of the soil profile. Unless the subsurface layers have dried beyond the point of compaction, tillage operations and associated wheel traffic

Aeration is directly related to the proportion of macropores in the soil.

Continuous cropping, grazing, Na and K application, and tillage, can, over time, contribute to the breakdown of macropores and reduction of aeration capacity.

can easily destroy macropore space beneath the tilled layer, impairing downward movement of air and water. Such damage is not easily overcome, even by subsoiling.

Hydraulic loading: Excessive hydraulic loadings lead to filling of soil pore space, a displacement of soil gases, and a great reduction in gas diffusion. The plant growth can be severely retarded if this condition persists for any length of time and removal of BOD_5 and COD waste organics becomes impractically slow. Clearly, rapidly drained soils are best suited for the maintenance of adequate aeration.

Excessive hydraulic loading and soil surface clogging impede aeration.

Surface clogging: The formation of a compacted, tightly sealed surface layer will prevent gas diffusion and the subsequent aeration of soil. Surface clogging is a problem with some wastes (such as from milk products) and some raw sewages (Kirkham, 1974). Resting periods often promote the drying, crumbling and dissipation of such surface caking (Mioduszewski and Hinesly, 1972).

Sludges often are plowed under to control odor and to prevent surface caking. Sludges also may be applied through subsurface injection procedures. These practices maintain soil infiltration rates and offer odor control, but biological degradation of organics is impeded somewhat. This obstruction is caused by the lower temperature and oxygen concentrations of subsurface soils.

Nonbiodegradable organics: The organic matter associated with food processing and municipal wastes usually poses no fundamental biochemical problem to soil systems. Manufactured organics, on the other hand, may be considerably less compatible with the biochemical processes of soils. Petroleum and tar-based synthetics including crankcase oils, pesticides, PCB, detergents, solvents, and so on may persist for a long time.

Nevertheless, these organics appear to adhere to surfaces of soil particles. They remain relatively immobile on all but very sandy soils. Any migration occurs through erosion.

Synthetic organic compounds are often not readily decomposed like natural organics. They may persist for long periods in soil but are generally immobile.

For most such products (PCB being a notable exception), biodegradation does occur with time, leading to secondary or tertiary products which are most likely to enter into natural cycles of soil organic matter (Mansell, et al., 1970; Kirkham, 1977; Fink, et al., 1970; Brady, 1974). Instances have been reported, however, where a "tar-like" layer about 1.5 feet thick developed about 1 foot beneath the surface of high rate infiltration beds. Such deposits had to be dug out before soil infiltration capacity could be restored (Satterwhite, 1974). Apparently such oily layers are, as yet, relatively rare and their causes remain unknown. Nevertheless, the presence of appreciable quantities of persistent organics might better be avoided.

In rare instances, oily substances have collected in a layer in rapid infiltration basins.

Recapitulation:

Although data are limited, it appears that very large BOD_5 loadings can be degraded in soils so long as soil aeration is maintained. It is quite likely that nitrogen, toxic elements, or hydraulic loadings become limiting in land application before organics. Adequate aeration is associated with well drained soils of sufficient macropore space with no surface clogging and adequate resting periods. Even high loads of food processing wastes ($>$ 8,000 lbs COD/acre-day) have been renovated without excessive losses ($<$35 mg/l) of organics to groundwater.

Incorporation of Stable Organic Matter in Soil

It is well known that organic matter tends to accumulate in and disappear from soils. For example, mineral surface soils carry native organic matter in concentrations ranging from trace quantities to 15 or 20%. Organic soils (peats, mucks, etc.) may range upward to 90% organic matter (Brady, 1976). It is natural, therefore, to consider the organic matter in wastes and its effect on both the quality of the soil and the net accumulation of organic matter in soils.

Mineral soils contain between a trace and 15 or 20% organic matter. Organic soils can have up to 90%.

Before such questions can be addressed, a perspective is needed on the relation of native organic matter to the soil system. Waste organic matter then can be considered in terms of its ability to be integrated into the natural system.

Soils and Native Organic Matter:

The major source of native organic matter is the decomposition of vegetation. The components of vegetation vary widely in their rates of decomposition as is indicated in Figure 9. Compare these with components of untreated domestic wastewaters given in Figure 1. Notice that many of the same classifications of compounds appear in each list. Also, note the longevity of some of the forest litter compounds.

Most native organic matter in soils comes from decayed vegetation, which can vary in decomposition rate.

Decomposition of organic matter: The decomposition of organic matter, whether from vegetation or wastes, is tightly bound to the ratio between carbon and nitrogen in the organic substrate. Normally, optimum decomposition rates occur when the C:N ratio is around 10:1. Other parameters also must be favorable, of course, such as temperature (about 30°C), moisture (60 to 80% field capacity), and aerobic conditions.

If a substrate such as corn stalks is incorporated into the soil, its high C:N ratio (50:1) may lead to

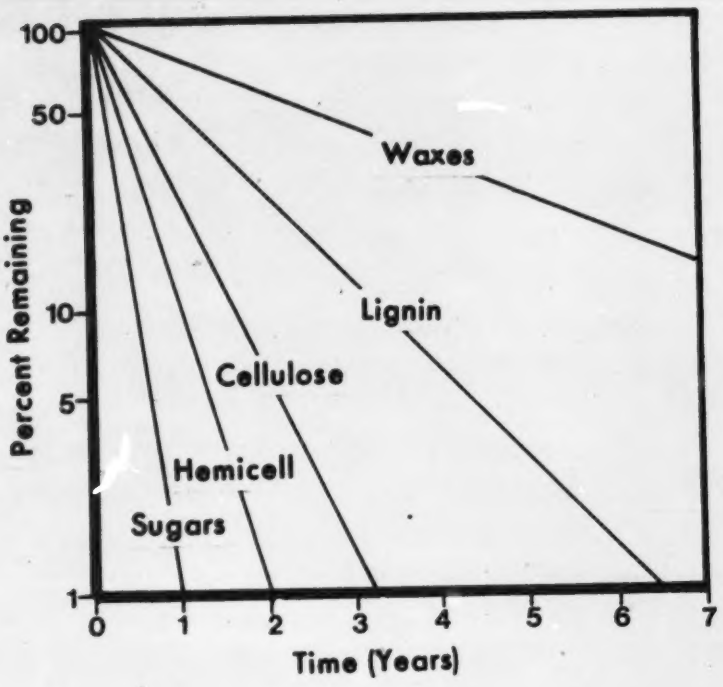

Figure 9

The rate of decomposition of organics of forest litter varies with the nature of the organic matter (adapted from Wallace, 1976).

slow decomposition (Parr, 1974) and nitrogen deficiency for rooted plants. This is particularly true if no residual nitrogen fertilizer is in the soil. The effect is even more pronounced when straw is used. What happens is that the small amount of available nitrogen cycles continually within the microbial population while organic carbon is respired as carbon dioxide. No nitrogen is available for rooted plants (which are poorer competitors for nitrogen than microorganisms) and carbon is gradually lost, narrowing the C:N ratio down until it approximates the optimum range.

Under aerobic conditions, organic matter decomposition is fastest at a C:N ratio of about 10:1.

On the other hand, substrates such as manures or municipal wastewaters generally have very narrow C:N ratios. The decomposition of organic matter is again slowed while nitrogen is mineralized. This process leads to the release of ammonia (NH_3) and nitrate ion (NO_3^{-1}). If this supply of nitrogen is in excess of the needs of rooted plants, nitrogen toxicity of vegetation and contamination of groundwater may result. At any rate, nitrogen losses lead to a widening of the C:N ratio and, again, an approach to optimum conditions.

Accumulation of native organic matter: In some 550 surface mineral soils summarized by Brady (1974), the average concentrations of organic matter ranged from 1.55 to 3.83%. Those concentrations represent from 15.5 to 38.3 tons of organic matter per acre-furrow slice (6 inches deep). Mineral subsoils generally carry substantially less organic matter. These values represent a reasonably steady-state balance of organic matter in which annual additions approximate annual losses.

Normally, annual organic matter additions equal depletion in mineral soil.

The magnitude of annual losses are estimated at roughly 450 pounds of organic matter per acre-year from untreated, low-producing soil and some 6,800 pounds per acre-year from more productive soil (Brady, 1974; Russell and Russell, 1950). It is only under conditions of anaerobic life, peat formation, or initial colonization of a denuded landscape that carbon accumulation (from natural vegetative growth) exceeds decomposition (Ghilarov, 1967).

Production of humus: The most persistent carbonaceous forms appear, in time, as chemically complex matter composed of oils, fats, waxes and especially lignin on one hand and metabolically produced polysaccharides and polyuronides on the other. Altogether, these substances are called humic matter and the

resulting chemical complex is known as humus (Brady, 1974). Humus is brown to dark brown in color, a collection of amorphous and colloidal substances, and with mean residence times in soils reported from >300 to >1500 years (Campbell, et al., 1967; Brady, 1974). Humus has C.E.C. values considerably in excess of mineral colloids (150-300 meq/100 g for humus compared to only 8-150 meq/100 g for minerals) (Brady, 1974). Humus is important in the removal of toxic elements from the soil solution, particularly copper and nickel (Chaney, 1974). This is discussed in more detail in Module 11, "Potentially Toxic Elements".

Humus is high in C.E.C. and is very important in binding metal ions. Humus also stabilizes soil structure by preventing clod formation.

Influence of organic matter on aggregation: Various kinds of organic matter (chiefly polysaccharides and breakdown products of humic substances) and numerous organic substances act as binding agents for soil aggregation. Aggregate stabilization, however, depends on the presence of non-aggregating matter between aggregates. In this respect, large spherical humus molecules (among other soil substances) act as important aggregate stabilizers by keeping aggregates separate and preventing their fusion into clods (Allison, 1967).

Soil and Waste Organics:

The above discussion presents an overview of the sources, magnitudes, and fates of native organic matter in soil systems. Since much of the organic matter in untreated municipal wastewaters is chemically similar to native organics, the following discussion on waste organics is closely related to what already has been covered. We will now focus on questions of organic matter accumulations, effects on soils, and hazards.

Magnitude of organic matter application; While there is no maximum load of oxygen-demanding organics

established by empirical studies, sludges and manures are usually applied at from 10 to 20 tons/acre-yr. (Loehr, 1974). Parr (1974) stresses the need to seek optimum application rates of sludges rather than "maximum" rates, yet he suggests that 10 to 20 tons dry sludge/acre-yr. is reasonable while 50 tons dry sludge/acre-yr. would probably create severe hazards from nitrogen pollution (not organic overload).

The most important factor that prevents any sizable accumulations of waste organics is that the actual amount of organic matter applied to the soil is relatively low. This may seem surprising if one thinks of adding, say, 10 tons of moist sludge per acre. Consider, however, that a mineral soil carrying 4% organic matter will contain 160 tons of native organic matter per acre - 2 feet, assuming a uniform distribution of organic matter throughout the soil. On the other hand, this 10 tons of moist sludge (assuming its nitrogen content is similar to farm manures) contains only about 5000 pounds of dry organic matter (Brady, 1974). Thus, the applied organic matter represents only about 1.6% of the organic matter already present in the soil and some of that addition will decompose. Plowing under residue from cereal crops is no better. The estimated return ranges to about 4460 pounds of organic matter per acre-year (Shields and Paul, 1973). Yet these values may be compared to Brady's estimate that a productive soil of the type described here may respire an equivalent of some 8000 pounds of organic matter per year. Also, recall the previously cited estimate of Jewell and Loehr (1975) that at least some soils have the capacity of oxidizing single slugs of certain food processing wastes containing organic matter loadings of equivalent to some 8000 pounds COD per acre-day.

Recommended sludge application rates represent a small percentage addition annually to the native soil organic content.

Sludge organic matter addition may be comparable to plowing under cereal crop residue, and less then that lost in a productive soil annually.

Of course, real soils cannot be expected to have a uniform distribution of organic matter through a

two foot column, nor will respiration processes be uniform throughout that column, but it is clear that, at the very best, those applications of organic matter barely balance losses from active soils. But as much as 80% or so of the added organic matter may be oxidized rapidly as described earlier. Thus, 80% of the organic matter would have no significant residence time and therefore would make accumulations of organic matter even less likely. This is illustrated in Figure 10. Consider how much Figure 10 would be altered if the application was, say, equivalent to 20, 50, or even 200 tons of manure or sludge (at 25% organic matter).

Organic loss through carbon respiration: Respiration of organic matter is not limited to native material. Newly added organic matter soon will begin to be lost. Jenkinson (1971) indicated that about two-thirds of carbon added in one year as cereal straw (a substrate of high C:N ratio) was respired by the following year. After five years about four-fifths of the original carbon was gone. Shields and Paul (1973) studied ^{14}C labelled wheat straw and grasses on two different soils and showed that soils, crop and cropping practices influenced the decomposition rates but, in general, the half-life of straws was 24 months and 48 months whereas resistant grass had a decomposition half-life of about 96 growing months. Jenkinson (1965) also provided other evidence that newly applied carbon was less resistant to degradation than native soil organic matter.

Nitrogenous wastes and their decay rates: Sludges and manures usually are substrates of low C:N ratios. Their rates of decay are given as the familiar decay series discussed in the Appendix of Module 15, "Nitrogen Considerations". Some typical decay series values are given in Table 1.

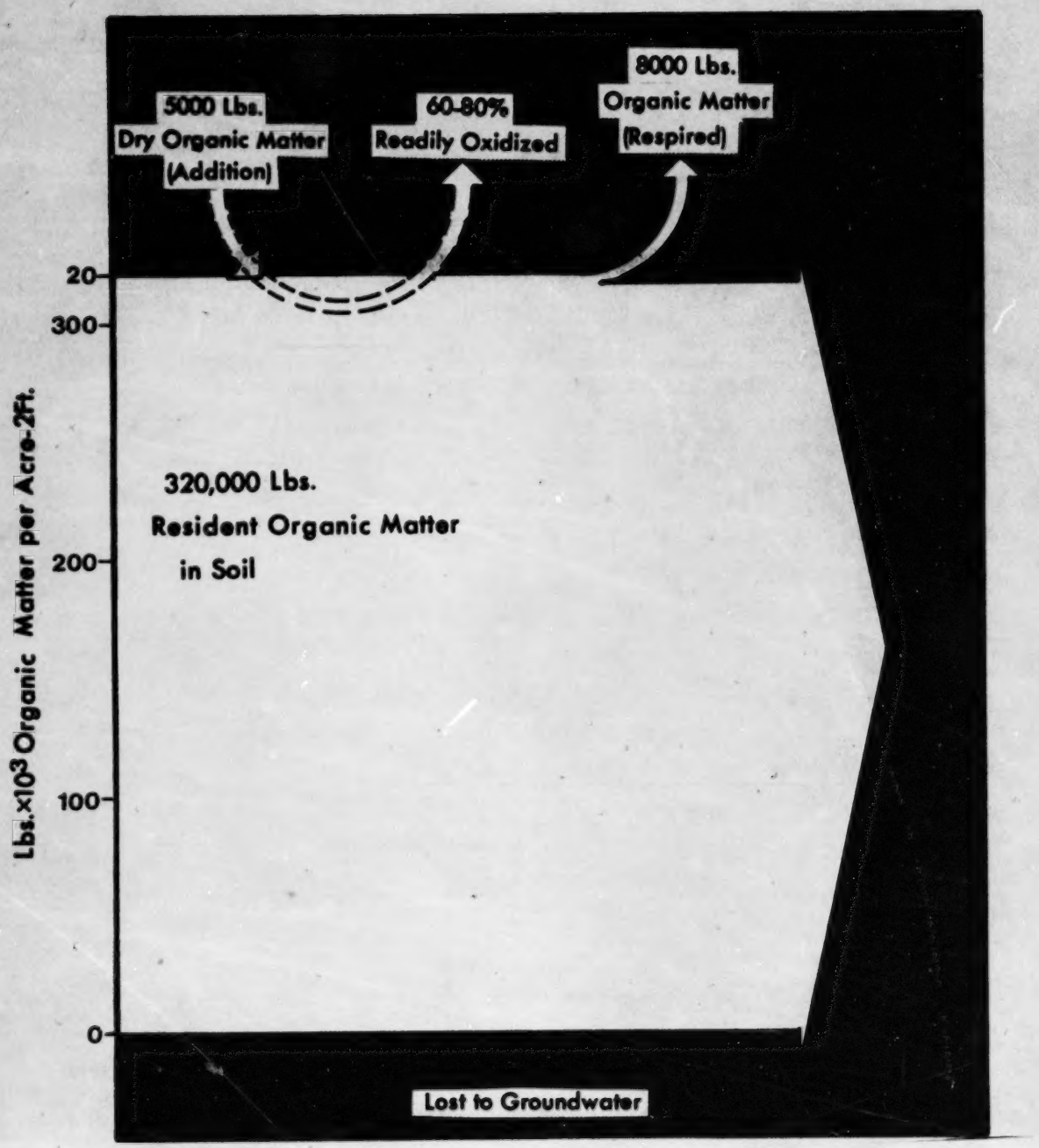

Figure 10
The magnitude of the organic matter added to soil is small compared to quantities of native organic matter, and losses due to normal respiration in the waste make net accumulation unlikely.

Table 1

The Rate of Mineralization of Nitrogen from Substrates Varies with Each Substrate as Indicated by Their Respective Decay Series.[a]

Substrate	Range of % N in Dry Material[b]	% N in Sample of Given Decay Series[c]	Decay Series
Sewage Sludge	2.0-6.0	2.5	0.35, 0.10, 0.06, 0.05, 0.04, 0.03
Dry Feedlot Manure	1.2-2.0	1.5	0.35, 0.15, 0.10, 0.05
Fresh Feedlot Manure	2.4	3.5	0.75, 0.15, 0.10, 0.05

[a] Decay series is the ratio of the fraction lost/fraction immobilized in successive years.

[b] Parr, 1974

[c] Pratt, et al., 1973

It is clear from Table 1 that the first year mineralization of fresh feedlot manures, for example, will release nearly twice as much nitrogen as would be released from sewage sludge. Thus, the decay series indicates that nitrogenous organic compounds do not have prolonged lifespans in the soil and that some pose a greater hazard to groundwater than others. Thus, there is a high rate of loss from soils and, therefore, the original application must be severely restricted to prevent nitrate contamination of groundwater. Both the loss rate and the restricted application rate work against possible accumulations of organics in soils.

Nitrogenous organic compounds can be degraded relatively quickly in soil. Application rates must be restricted to preclude NO_3^- loss to groundwater.

Changes in the physical condition of soils are favorable under proper sludge/manure application schedules. Notable among those changes is the enhancement of soil aggregation even in some tight clay soils (Kirkham, 1974). This in turn increases macropore space, improves soil aeration and creates favorable conditions for root growth. These same improvements are reported for sandy soils with the additional benefit of providing good binding material to prevent the sand from blowing away (Kirkham, 1974). Mine spoils, sand dunes and other barren matter having no significant indigenous organic matter will accumulate organic matter under wastewater/sludge irrigation. The final equilibrium which is approached will be site specific, and there is no evidence that it will reach the fertility of highly productive farming soils. Nevertheless, reasonably hardy grasses, trees, shrubs and cover crops have been grown on these irrigated soils, sand dunes have been stabilized, and erosion attenuated.

Sludge and manure are capable of altering physical characteristics of soils. Mine spoils, sand dunes, etc. can derive organics from applied wastes and support vegetation while reducing erosion.

The initial rate of accumulation of organic matter in raw mine spoils greatly exceeds any net accumulation that may occur in soils that already have a normal content.

In general, careful husbandry of soils, including the proper use of fertilizers, a judicious selection of crops, and the use of correct soil amendments can improve soil organic content somewhat, but even productive fields are likely to remain considerably lower in organic matter than nearly virgin soil (Brady, 1974).

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ORGANIC MATTER

Objectives

Upon completion of this module, the participant should be able to indicate:

1. The three categories into which organics can be divided.
2. The differences between acclimated and unacclimated soil in its reaction to the addition of organics.
3. The removal efficiency of land application systems in relation to BOD and COD.
4. The importance of a resting period in relation to the treatment of organics.
5. The significance of the C/N ratio as it relates to organics in sludges and wastewater.
6. The loading rate for sewage and sludge in relation to the organics.
7. The relation between sewage sludge and mine spoils.

RETURN TO LESSON PACKAGE

Script to Accompany the A-T

ORGANIC MATTER

Module 17

January, 1978

ORGANIC MATTER

(Slide 1) This module concerns the application of sewage organic matter to the soil. The lesson first classifies the different types of organic matter found in wastewater, indicates the fate of the organics in land treatment practices necessary for the successful treatment of organics in wastewater and sludges (Slide 2). The objectives for this lesson are located in an envelope that was in the box with this tape. The envelope is labelled, "Objectives for Organic Matter". Find and study the objectives(Slide 3). When you have finished studying the objectives, turn the recorder back on. You may keep the objective list for reference during the lesson.

Organics in wastes are a key design factor in conventional treatment because of the oxygen demand they impose (Slide 4) on the treatment plant and receiving waters. This oxygen demand is caused by the microorganisms that oxidize the organics. As this lesson will show, organics rarely pose a problem in a well managed land application system.

Initially, organics can be divided according to their solubility, as in Slide 5. The soluble organics exert the most rapid oxygen demand. Both soluble and particulate organics are measured in the familiar five day biological oxygen demand test when raw wastewater is used. Occasionally, wastewaters of municipalities or food processing industries carry chemicals that may or may not be organics which exert a high chemical oxygen demand. These also could be soluble.

Insoluble organics can be categorized as in Slide 6. A portion of these insoluble organics can be degraded, and at that time would exert an oxygen demand. This oxygen demand may not be totally exerted in a five day biological oxygen demand test using untreated wastewater. It could be exerted after the five day period, generally used in the conventioanl BOD test as indicated in Slide 7. This may coincide with the oxygen demand that is exerted by the oxidation of nitrogen. This latter oxygen demand is called nitrogenous oxygen demand. With treated wastes, the onset of this oxygen demand (NOD) may occur within the five day period, as shown in Slide 8, since there may be adequate nitrifying organisms in the treated wastes. Only a portion of this oxygen demand of treated wastes may be caused by organics, with most of the demand being exerted by the nitrification of ammonium to nitrate (NOD).

The third category of organics (Slide 9) includes the less active, usually insoluble organics with no rapid demand for oxygen. When necessary, the impact of these organics may be estimated indirectly by the measurements indicated in Slide 10. This slide also indicates the quantitative relationships among the various measures of organics.

For the purposes of this module, the familiar five day BOD data, which will be simply called BOD in the rest of the lesson, are useful for estimating the impact of readily degradable organic matter in land systems. This pattern of oxygen consumed over time is reporduced in Slide 11. Notice that there is a rapid uptake of oxygen in the first two days, and then there is a slowing down in the amount of oxygen consumed. Even after the initial rapid uptake, however, oxygen is still being consumed in the degradation of the organics. Slide 12 indicates the same information in a different way. This slide indicates the rate of oxygen uptake. Again, notice that the rate of oxygen uptake is highest during the first two days of incubation.

The previous two slides indicated the response from an acclimated population of soil microorganisms at 20°C. Slide 13 indicates the response of an unacclimated population of soil microorganisms to the addition of organics. Notice that the total amount of oxygen utilized remains the same but the response time is much slower. This lag is important when a land application system is started up. Application schedules must be adjusted to give the soil population a chance to acclimate to the applied organics.

Amending soils with high BOD wastes poses a stress on the available oxygen within the soil system. So long as that oxygen demand can be met, the BOD load will not be excessive (Slide 14). But meeting that load requires the interaction of several complex events. In this section attention will turn first to the response of soils to BOD loading, then to a discussion of factors that influence that response. As an introduction, and to keep the addition of organics to the soil in perspective consider Slide 15. The 6000 lbs of BOD is the amount that would be added per acre-year with untreated wastewater containing 250 mg/l BOD applied at a rate of two inches a week. Notice that 60% of the added organics would be consumed almost immediately, and the amount of organics remaining is insignificant compared to the resident organics in the soil. The next section will indicate the consequences of adding much higher loadings of organics to the soil.

One study reported oxygen uptake rates for both acclimated and unacclimated soils under various COD loadings. These results are indicated in Slide 16. Note that in each case the respiration has reached its maximum in less than two days. Their results at various loadings are indicated in Slide 17. Some states arbitrarily limit BOD loadings to 600 lbs/acre-day and further information is needed on applicable organic loading rates. It was concluded that the soils in this study retained the potential of accepting food processing wastes at concentrations of 10,000 mg/l of COD without suffering organic overloading. That would equal about 4500 lbs COD per acre-day if applied at two inches per week.

The data in Slide 16 and 17 were obtained using food processing wastes. Other studies have indicated overloading at lower rates of application. Overloading at 1000 lbs BOD/acre-day are indicated in Slide 18. This data is from a study using sulphite liquor waste. The comparison of data in this slide with the previous slides should indicate the importance of the type of waste when considering land application and the different land application systems.

As was indicated earlier and repeated in Slide 19, the maximum rate of oxygen uptake occurs in the first forty-eight hours. Notice, however, that even after 5 days respiration is continuing in the test samples. Most of the organic matter that is oxidized is converted to gums, slimes, protoplasm and other metabolic by-products. These by-products have important roles in the formation of soil aggregates before they, too, are degraded. Also during this time, a portion of originally insoluble organics is being converted to soluble forms. These factors should cause concern for the possibility of groundwater contamination. As Slide 20 indicates, however, even at loadings of 8000 lbs COD per acre-day, greater than 99% removal was achieved and less than 4 mg/l BOD reached groundwater.

This however, may not be the case in all high organic loading situations. If anaerobic conditions exist in the soil, a different situation prevails. In Slide 21 notice that only about 10% of the BOD may be removed when the soil has become anaerobic. In this situation, the soluble organics would present a hazard to groundwater. It is clear, therefore, that the bio-oxidation of organics depends upon the passage of oxygen into the soil, thus maintaining aerobic conditions.

Slide 22 indicates the mechanism of diffusion of oxygen into and carbon dioxide out of the soil. Even though the total gas pressure is the same on both sides of the soil-air interface, indicated by line A, the partial pressure

of the individual gasses determines the direction of movement of those gasses. The movement of oxygen and carbon dioxide depends on three main factors as illustrated in Slide 23. These are depth, macropore space, and the composition of the soil and atmospheric air. Notice that the potential for diffusion is greater closer to the soil surface. Since the organics are filtered out in the first few centimeters of soil, they are located in an area that is potentially ideal for degradation. The next section will indicate ways of manipulating the application of waste and the site to maximize the aeration of the soil.

One necessity for the maintenance of aerobic conditions is the scheduling of resting periods. Slide 24 indicates several schedules of application and resting periods that have been used in various types of land application systems. The schedule chosen depends upon the time necessary for the soil to relieve its hydraulic load, and the optimum oxygen loading and consumption for the particular waste, among other factors. Since these factors are site specific, few general guidelines can be given and it may be necessary to consult a qualified soil scientist for this determination.

Perhaps the most important soil feature affecting aeration is macropore space. In its natural, undisturbed condition, a silt loam soil is preferable to a finer textured soil because of the tendency for the silt loam to have a larger proportion of macropores. There are methods, however, for maintaining and even improving the proportion of the macropores in any type of soil. Loosening and granulating (Slide 25) fine-textured soils promotes aeration by raising the proportion of macropores. Slide 26 indicates, however, that continuous cropping especially with an annual like corn, decreases both the amount of organic matter and macropore space. The rotation of crops, as opposed to a succession of the same annual crop, also promotes macropore formation and maintenance as indicated by the percent of large aggregates in Slide 27. There are other factors that affect the pore space which can be found in various modules throughout this series (Slide 28).

Excessive hydrualic loadings and saturated conditions lead to filling of soil pore space, a displacement of soil gasses and reduction of gas diffusion. The permissible hydraulic load depends upon several factors. These include the structure and texture of the soil, the amount of evapotranspiration, the depth to groundwater, and the available water capacity. Slide 29 indicates the modules that deal with each of these areas.

The formation of a compacted, tightly sealed surface layer will prevent gas diffusion and the subsequent aeration of soil (Slide 30). Surface clogging or surface compacting can be caused by different factors as indicated in Slide 31. It can be a problem with some wastes, such as from milk products and with rapid infiltration systems using over five feet of untreated wastewater per week. Resting periods will often promote the breakdown of the material clogging the surface but compaction casued by animal or machinery traffic is often resistant to rejuvenation, The same processes that promote the digestion of organics in wastewater promote the breakup of sludges applied to the surface of the soil. Slide 32 shows the application of the sewage sludge that is a product of the Chicago sewage treatment facility.

As previously indicated in this lesson, it is important to consider the state of acclimation of the soil for the treatment of organics. Slide 33, which was presented previously, indicates that organics are not decomposed as rapidly by unacclimated soil. Excessive loadings at this site could clog the soil resulting in anaerobic conditions with resultant odors and loss of treatment potential.

Organic matter associated with food processing and municipal wastes usually pose no fundamental biochemical problem to soil systems. Manufactured organics, on the other hand, may be considerably less compatible with the biochemical processes of soils. Slide 34 indicates the half life in soils of several organic pesticides. Other synthetic organics include crankcase oils, detergents, solvents and the almost indestructible PCB's. These organics appear to adhere to the surfaces of the soil particles, and remain relatively immobile. As Slide 34 indicates, biodegradation does occur with time for most of these organics leading to secondary or tertiary products which are more likely to enter into natural cycles of soil organic matter. Nevertheless, it is important to monitor for appreciable quantities of persistant organics and limit their entry to soil application systems if they become hazardous to the environment or the conditions at the site.

In summary, it appears that very large quantities of BOD can be applied to the soil and degraded as long as aerobic conditions are maintained. In dealing with municipal wastes and most industrial wastes, it would seem that other factors, especially nitrogen as indicated in Slide 35, would become limiting before organics would pose a problem. The next section deals with the fate of organics in soils.

It is natural to wonder about the consequences of long term application of organics to the soil. Slide 36 indicates the rates of decomposition of natural vegetation. Notice that not only are there several similar components between native organic matter and the organics in wastewater, but that the decomposition rates vary with the solubility of the vegetative components as do the organics in sludge and wastewater. Therefore, the addition and consequent fate of natural waste organic matter is much like the fate of native and agricultural organic matter.

The decomposition rate of organic matter is closely related to the ratio between carbon and nitrogen, called the C to N ratio. This ratio is relatively constant in soils of a similar area and depends to some extent upon the soil temperature and moisture. In humid regions the ratio is about 10:1. Slide 37 indicates the C to N ratio for wastewater, sludge, and various agricultural crops. When the C:N ratio is high there is keen competition among the soil biota and vegetation for the available nitrogen, leading to nitrogen deficiency in crops and limiting the degradation of the organics. This would be the case with agricultural crop residues such as straw, animal bedding, and similar carbonaceous material. Notice, however, that municipal waste and sludges have a low C:N ratio. In situations like this, nitrogen is mineralized leading to the release of ammonia and nitrates. If the excess nitrogen is not taken up by the plants it may result in the contamination of groundwater from nitrates, as discussed in Module #15, "Nitrogen Considerations." The final result, with initially high or low C:N ratios is the same - a return to about the 10:1 ratio. As slide 37 indicates, excess nitrogen will become a problem with municipal and most industrial wastes and sludges before the organics become a problem.

As the organics decompose, humus is formed. Slide 38 is a photograph of humus material. It is a collection of amorphous and collodial substances composed of the material indicated in Slide 39. Notice that humus is made up of the persistant organics and metabolically produced substances. Humus is important and beneficial for several reasons, indicated in Slide 40. Notice the cation exchange capacity of humus. This is several times the C.E.C. of most clay soils and is very important for the removal of potentially toxic elements. This is discussed fully in Module 3, "Soil as A Treatment Medium" and Module 11, "Potentially Toxic Elements".

This discussion has centered around the addition and fate of organic matter from native sources, from agricultural sources and from municipal wastes. There has been no loading rate indicated for organics. It has been suggested by some

investigators that 10 to 20 tons of dry sludge per acre year would be reasonable, while 50 tons might be excessive, but not because of organic loading. More than fifty tons would be hazardous because of the danger of nitrogen pollution. It may seem that twenty tons is a lot of organic matter, but consider Slide 41, a portion of which was shown earlier. In a soil containing 4% organic matter, there would be 160 tons of organic matter in an acre two feet. If the 20 tons of sludge contained 25% organic matter that would only be an addition of five tons with about four of those tons being oxidized and digested in a matter of days.

Changes in the characteristics of low organic soils can be favorable under proper sludge application schedules. Aggregation formation can be improved in both a tight clay soil and a very loose sandy soil by the judicious use of sludge. In both cases, favorable conditions for root growth will be increased. Slides 42 through 45 indicate the consequences of applying wastewater and sludge to mine spoils. Vegetation will grow where none grew before. The final equilibrium which is approached will be site specific and there is no evidence that it will reach the fertility of highly productive farming soils, but an eyesore can be turned into a green area. The same results have been acheived with unstable sand dunes, resulting in stabiliaation. The initial rate of accumulation of organic matter in raw mine spoils greatly exceeds any net accumulation of humic material that may occur in soils that already have a noraml content of this constituent.

In summary, the organics that are applied to soil will, in general, not be a limiting factor. They will cause little accumulation of organic matter in soil with a normal content of humus and can be of benefit to land without enough native or natural organic matter.